INSTRUCTION MANUAL FOR

MODEL #301-A

ELECTRONIC MICROAMMETER

SERIAL #121

BETA ELECTRIC CORP.
NEW YORK, N. Y.

PLEASE NOTE:

Read the entire instruction manual thoroughly before attempting to operate the power supply.

If this is not convenient, please read the operating instructions completely before applying power for the first time.

OPERATING INSTRUCTIONS

for

MODEL 301 and 301-A

ELECTRONIC MICROAMMETER

BETA ELECTRONICS COMPANY

New York 29, N. Y.

(1) GENERAL:

The Model 301 ELECTRONIC MICROAMMETER is essentially a dc amplifier of moderate stability and gain, designed for general laboratory and industrial use. The instrument is completely self-contained, and operates from 117 volt mains. A compromise has been effected between size, cost and performance that results in a meter suitable for all applications where very high accuracy and stability are not required. When properly used, accuracy better than 3% of full scale is obtainable with short-time stability better than 2%.

The input sensitivity of the amplifier is 40 millivolts dc for full scale deflection of the output meter. To convert this dc amplifier to an ELECTRONIC MICROAMMETER, resistors are placed across the input terminals to develop 40 millivolts for the various full-scale current ranges. Thus, for 100 microamperes full scale, the input resistance is 400 ohms. ($400 \times 100 \times 10^{-6} = 40 \times 10^{-3}$) On the 10 microamperes full-scale range, the input resistance required to develop 40 millivolts is 4,000 ohms. The input resistance increases by a factor of 10 on each decade decrease in full scale current, so that on the 0.01 microampere full scale range the input resistance is 4 megohms. Where exact current sensitivity is unimportant, in such applications as null detection in dc bridges, the sensitivity can be made as high as 0.4 millivolts per division, or 0.0001 microamperes per division (20 millivolts full scale).

The most serious problem in the design of a dc amplifier for small current measurements is the reduction of grid current in the input stage tube. In most solutions to this problem, delicate, costly Electrometer tubes are employe The Model 301 utilizes an ordinary 6SC7 twin triode for the input stage; grid current is reduced by operating the plate and filament at voltages considerably below rating, and by careful design of the exact grid and filament voltage ranges. Residual grid current less than 0.0005 microamperes is present in all instruments. Care is taken in the construction of the meter to ensure negligible leakage to the input grid circuit from the various B+ circuits and cathode heater circuits.

Due to aging of tubes and circuit components, the calibration of a dc amplifier changes with time. In the Model 301, a simple calibration check is provided; the reference used is the output meter, thus eliminating standard cells or "zero drain" battery circuits.

The Model 301 ELECTRONIC MICROAMMETER has the great advantage over a wall galvanometer of being able to withstand enormous overloads without damage. (This is a property of most electronic measuring instruments.) In addition, the time of response of the Model 301 is considerably faster than a sensitive wall galvanometer, and is the same on all ranges. The Model 301 reaches final readings in less than 1 second. Finally, the Model 301 can take the roug physical handling of ordinary laboratory test instruments, whereas a sensitive wall galvanometer is mechanically delicate and must be handled with great care.

(2) DESCRIPTION OF CIRCUIT:

The circuit of the Model 301 ELECTRONIC MICROAMMETER, shown in Fig. 5, is a two-stage, direct-coupled dc amplifier, with cathode degeneration to provide negative-feedback. No "choppers", vibrating capacitors or other dc to ac conversion schemes are employed.

Twin triodes, VT2 and VT3, are used in each stage to minimize drift due to tube aging and power line voltage fluctuations. A VR tube, VT1, further serves to maintain stability against line voltage variations. A ballast tube, B.T., keeps the cathode emission of the tube in the first stage constant despite slow variations of line voltage, enhancing zero stability. The heater of the first stage is operated below rated voltage, thus reducing grid emissio and permitting more stable measurements on the 0.01 microampere scale.

Wire-wound resistors are used in all parts of the amplifying circuits for maximum stability and minimum dirft.

The operation of the circuit is as follows: a dc voltage of 40 millivolts applied to the left grid of the input stage amplifier (pin 4 of VT3) will cause full-scale deflection of the output 200 microampere meter, M, when P2 is properly adjusted. The current to be measured is sent through the "HIGH" and "LOW" input terminals, and the proper shunt, or input resistor, R13 through R17, is selected, so that the current being measured will generate between 4 and 40 millivolts across the resistor.

The internal calibrating circuit included in the ELECTRONIC MICROAMMETER permits a rapid check of the calibration of the instrument in a simple fashion. In essence, the 200 microamperes full scale output meter is first used to measure 100 microamperes flowing through the 400 ohm precision resistor R13 in the input circuit. This can readily be traced out in Fig. 5, considering SW3 to be in the "ADJ." position. Rheostat P3 controls the magnitude of this current. The meter is then switched back into the output circuit, and the voltage generated across the precision resistor by the current just measured is applied to the input of the dc amplifier. This is the case in the "CAL." position. The sensitivity of the amplifier is then adjusted by means of P2 to give the proper deflection on the output meter.

A polarity reversing switch, SW2, is included in the output circuit, so that no switching of input leads is necessary in case of reversal of current in the input circuit. Because of the sensitivity of the instrument, operation of the amplifying circuits takes place along linear portions of the triodes' characteristics, making the calibration on positive and negative inputs equal within the instrument's rated accuracy.

(3) OVERLOAD CONSIDERATIONS:

In case of a sudden increase of current being measured, or in case the input selector is on too sensitive a range, the output meter will not be damaged, due to the fact that the dc amplifier will saturate. Over-voltages within th power ratings of the input resistors will not damage these components. Accor ingly, over-currents of approximately 10,000% can be tolerated on all ranges. (See Note (10) for more details.) However, it is suggested that long-time overloads be avoided, as the stability and drift characteristics may be impaired. After a heavy overload, the zero may shift serveral percent, due to uneven heating of plate resistors, and may drift for several minutes.

(4) GENERAL OPERATING INSTRUCTIONS:

The "LOW" input terminal, which is connected directly to the return circuit of the amplifier, is insulated from the chassis and the case. Therefore,

operation is possible with the input circuit above or below ground potential. However, on the more sensitive ranges, leakage currents through the power transformer in the ELECTRONIC MICROAMMETER become of the order of magnitude of the currents being measured and reduce the stability and sensitivity of the instrument. Experience with the instrument will indicate to what extent measurements may be made with the input above or below ground potential.

In general, it can be said that MAXIMUM STABILITY AND ACCURACY ARE OBTAINED WITH THE "LOW" INPUT TERMINAL GROUNDED. The case need not be grounded, though increased stability will result on the most sensitive range if the case is grounded.

Accordingly, it is suggested that the Model 301 ELECTRONIC MICROAMMETER be used for different current-measuring applications as follows:

High resistance measurements or pre-breakdown current measurements in insulating materials: (Fig. 1)
One end of the power supply may be grounded and the "LOW" input terminal of the ELECTRONIC MICROAMMETER should be grounded. The high side of the power supply may be either positive or negative, and the polarity reversing switch of the ELECTRONIC MICROAMMETER should be set accordingly. In case of breakdown of the sample under test, the ELECTRONIC MICROAMMETER will not be injured even if the current should increase by a factor of 100,000, or more.
If it is desired to conduct a non-destructive breakdown test on the sample R_t, then a resistor of high resistance value, R_p, must be connected in series with R_t to limit the breakdown current as desired. In this case, the voltmeter used to measure the actual voltage at the test sample must draw very little current or else an excessive voltage drop will have to be borne by the protective resistor R_p. For these applications, the 50,000 ohms per volt Series 101 KILOVOLTMETERS manufactured by the Beta Electronics Company are suitable. Thus, if the sample is expected to break down at 15 Kv, and the maximum current is to be 50 microamperes, then R_p has to be 300 megohms. The Model 102 KILOVOLTMETER draws 10 microamperes at 15 Kv, so that the additional voltage needed at the power supply is only 3 Kv, because of the KILOVOLTMETER drain.
(The 0-30 Kv Adjustable dc POWER SUPPLY manufactured by the Beta Electronics Company is suitable for such high-resistance and breakdown voltage tests up to 30 Kv.)

Measuring grid current in vacuum or gas-filled tubes: (Fig. 2)
In this application, the plate power supply may be grounded, but a battery must be used in the grid circuit. If a power supply were to be used in the grid circuit, then leakage currents between the power supply and ground would affect the ELECTRONIC MICROAMMETER readings, especially on the more sensitive ranges. Therefore, a well-insulated battery must be employed and connected as indicated. The battery need not be tied to the grid directly; it may go to the grid through a potentiometer that is also well-insulated from ground. A voltmeter may be connected across the potentiometer to measure the grid voltage. Since the full-scale input voltage of the ELECTRONIC MICROAMMETER is only 40 millivolts, the voltmeter accuracy in most applications will not be affected by the ELECTRONIC MICROAMMETER resistance drop.
In general, it will be found that the insulation normally supplied around a dry-cell battery is sufficient. Mounting the potentiometer and voltmeter in

a good quality micarta panel will be adequate.
Since the battery is normally supplying currents of a few microamperes at most, the life is approximately shelf life, and frequent replacements are unnecessary.

Measuring pre-conduction current in a thyratron: (Fig. 3)
The precautions discussed above apply to this case as well. A battery must be used to supply the plate current, and the ELECTRONIC MICROAMMETER must be connected as shown. A dc power supply may be used in the grid if it is not desired to measure the grid current simultaneously.
With the ELECTRONIC MICROAMMETER measuring the pre-conduction current as shown, R_L may be low enough to permit rated current to flow in the thyratron after the tube fires. The ELECTRONIC MICROAMMETER will not be damaged in any way if, for example, a 2050 thyratron is being tested, and the 100 microampere full scale range is used, with a battery of 150 volts and 3,000 ohms load resistance. The current may jump from 15 microamperes to 0.05 amperes without damaging the output meter. The general precautions with respect to overload discussed in section (1) should be observed.

Measuring plate current in Ionization Vacuum Gauge: (Fig. 4)
In this application it is desirable to ground the plate of the ion gauge tube through the input to the ELECTRONIC MICROAMMETER. The cathode may be maintained at proper negative voltage and the grid at proper positive potential by means of suitable dc power supplies. (See note (5) for further information on this type of application.)

Other low-current measuring applications will usually be essentially similar to one of the four just described. The precautions discussed for each should be observed.

(5) STABILITY:

With the case and input terminals grounded, visible zero drift will cease after 10 minutes of warm-up. After 1 hour, zero drift is less than 6% of full scale per hour, depending on the particular circuit components.

Slow line voltage drifts between 105 and 125 volts will not affect the calibration, and will cause zero drifts of less than 5% of full scale. Sudden line fluctuations may cause larger zero drifts, mainly because of disturbance to the input tube heater. If violent line voltage fluctuations are possible, it is recommended that the ELECTRONIC MICROAMMETER be operated from a stabilized ac power source, of 40 to 60 volt-ampere rating of either the magnetic or electronic regulating types.

The zero shift from the least sensitive to the most sensitive ranges will be less than 5% of full scale deflection on the most sensitive range, for the Model 301, and less than 3% for the Model 301-A. This represents less than 0.001 microampere, and is thus difficult to interpret. This shift is a function of temperature, humidity, tube conditions, etc. Since the current is so small, it may represent current flowing in the input circuit through leakage paths from a nearby power supply. In any event, the zero shift between extreme ranges is usually less than 3% of full scale. Therefore, the range switch may be set on the 0.01 range to measure less than a hundredth of

a microampere, and, if the current should suddenly rise to anything less than 100 microamperes, the range selector may be operated to bring the needle on scale, and the reading may be recorded without having to short out the input and reset the zero. If the tests to be made will require readings only on the 0.01 microampere range, then it is recommended that any zero shift encountered between this range and the 100 microampere range (the setting at which the instrument is calibrated) be balanced out by means of the zero control. The accuracy of the instrument will not be effected by resetting the zero on the 0.01 microampere range. If the tests will require shifting from the 0.01 microampere range to other ranges, then it is recommended that the zero shift on the 0.01 range not be balanced out. Instead, the zero error should be recorded and the data corrected on the 0.01 range.

The zero shift on the 0.01 range may be either positive or negative. If positive, it may be read with the polarity reversing switch in the (+) position. If negative, it may be read by turning the polarity switch to the (-) position.

Most of the zero shift between extreme ranges occurs on the 0.01 range. For work on other ranges, generally speaking, the zero balance will not be disturbed visibly by shifting between the 100, 10, 1 or 0.1 microamperes scales.

(6) ACCURACY:

When properly calibrated and zeroed, and when used as recommended in the GENERAL OPERATING INSTRUCTIONS section, the full-scale accuracy is better than 5% on all ranges for the Model 301, and 3% for the Model 301-A, except possibly the 0.01 microampere full-scale range. On this latter scale, an additional error of 5% for the Model 301, and 3% for the Model 301-A, may be introduced, due to zero shift discussed above. However, the zero shift may be balanced out be means of the "ZERO ADJUSTMENT" control, in which case the precision is then the same as that on other ranges, for both models. The instrument's accuracy is determined by the precision of the output meter and the input resistors. The latter are selected for better than 3% tolerance in the Model 301, and 1% in the 301-A. The meter has a 2% full-scale accuracy, and is calibrated for 1% precision at the midscale, or 100 microampere point.

****

(7) OPERATION PROCEDURE:

Check mechanical zero of meter. Then, with the input terminals disconnected from the circuit under test: (The "LOW" terminal and the case may be left grounded, but the "HIGH" terminal must be free.)

(a) Connect the ELECTRONIC MICROAMMETER to a 117 volt 50/60 cycle source by means of the line cord and the 61M10 plug. This simultaneously energizes the 2-prong 61F outlet which may be used for auxiliary equipment such as a soldering iron, cathode-ray oscilloscope, etc.

(b) Throw toggle switch to "ON". This illuminates the pilot light and turns on the amplifier. Allow a warm-up period of at least four minutes

before proceeding with the calibration process.

(c) TO CALIBRATE:

I. Set the (+ -) switch to (+); set the "CALIBRATE OPERATE ADJUST" switch to "ADJUST"; set the Range Selector switch to "100-CAL."

II. Adjust the "CALIBRATION ADJUSTMENT" control until the meter reads exactly half scale, which is 0.5 microamperes on the dial face. (This measures 100 microamperes flowing through the 100 microamperes input position.)

III. Turn the "CALIBRATE OPERATE ADJUST" switch to "OPERATE", and bring the meter needle to zero by means of the "ZERO ADJUSTMENT" control. Zero may be checked by operating the (+ -) switch back and forth. If zero is properly adjusted, there will be negligible deflection of the indicating needle on the meter as the polarity reversing switch is operated. (The switch must be left in the (+) position for the remainder of the calibration.)

IV. With the zero properly balanced, and the polarity reversing switch at the (+) position, set the "CALIBRATE OPERATE ADJUST" switch to "CALIBRATE". (The range switch must be at the "100-CAL." position.)

V. Adjust the "SENSITIVITY" control for full-scale deflection.

VI. Return the "CALIBRATE OPERATE ADJUST" switch to the "OPERATE" position, and reset the zero, if necessary.

(d) If the zero shifted more than a few percent during steps (IV) to (VI) of the calibration procedure (due to calibration being attempted before the instrument has warmed up sufficiently), then steps (III) to (VI) will have to be repeated.

(e) If the zero shift noted after step (VI) was less than 2 or 3 meter divisions, then the instrument is sufficiently warmed up and is ready for use. Connect into the circuit under test, observing the precautions outlined under "GENERAL OPERATING INSTRUCTIONS," section (4).

(f) For positive currents, set the (+ -) switch at (+). For negative currents set the (+ -) switch at (-). (The current direction should be determined with the "LOW" terminal grounded.)

(8) FOR USE AS A NULL-DETECTING GALVANOMETER:

It is not necessary to go through the calibration process of (c) if the ELECTRONIC MICROAMMETER is to be used as a null-detecting galvanometer. It is only necessary to go through (7a) and (7b). After visible drift has

stopped, turn the sensitivity control all the way CLOCKWISE; this will give a full-scale sensitivity of approximately 20 millivolts, or 0.4 millivolts per division. The current sensitivity is then determined by the range selector, ranging from approximately 1.0 microampere per division on the 100 microampere full-scale range, to 1/10,000 microampere, or 10^{-10} amperes per division on the 0.01 microamperes full-scale range.

The long-time stability is reduced when the sensitivity is increased for null-detection. However, this is generally unimportant, as only momentary deflections of the indicating needle are sought.

****

(9) TUBE REPLACEMENTS:

All the tubes are operated well below their maximum ratings, and so should last for many thousands of hours. The VR tube, the ballast tube and the 6SN7 can be replaced without affecting the characteristics of the ELECTRONIC MICROAMMETER noticeably. However, replacing the 6SC7 may require tests with two or three tubes before a satisfactory one is obtained. When replacing the 6SC7, the following requirements must be satisfied:

(a) The two triode sections of the tube must be well enough balanced so that the meter can be brought to zero, with the function control in the "OPERATE" position, by means of the "ZERO ADJUST" control.

(b) The grid current must be below 0.0005 microamperes, or, the zero shift from the 100 microampere range to the 0.01 microampere range (with the instrument properly calibrated) must be less than three meter divisions.

When changing the 6SC7, first requirement (a) must be satisfied, and then requirement (b) can be met. The characteristics of the 6SC7 can be controlled to a large degree by changing the heater voltage. To this end, the rheostat P4 is included in the circuit to effect control of the 6SC7 characteristics.

After the new 6SC7 has been put in place, proceed as follows:

(a) Allow a warm-up period of five minutes. See if the meter can be zeroed by means of the "ZERO ADJUST" control. If the meter can be brought to zero, then proceed with steps (b) en suite. If the meter cannot be brought to zero, then:

I. Turn the screwdriver-controlled rheostat, on the right side of the chassis, all the way counter-clockwise. See if the meter drifts past the zero. If it does, then return the needle to zero by means of the "ZERO ADJUST" control, and proceed with steps (b) en suite.

If after step (I) the needle still cannot be brought to zero, then:

II. Turn the screwdriver-controlled rheostat all the way clockwise. See if the meter drifts past the zero. If it does, see if the "ZERO ADJUST" control can bring the needle back to zero. If the meter can be zeroed, continue with steps (b) en suite.

If the meter cannot be brought to zero by means of the "ZERO ADJUST", and if the needle does not drift past zero with the screwdriver-controlled rheostat in the extreme counter-clockwise and clockwise positions, then the tube must be discarded. However, if the meter stays off zero in one direction with the rheostat all the way in, and stays off zero in the other direction with the rheostat all the way out, and the "ZERO ADJUST" cannot bring the needle to zero, then there must be an intermediate setting of the filament heater voltage control rheostat where balance can be achieved by means of the "ZERO ADJUST." Find this balance point by trial and error, and proceed with steps (b), en suite.

With the meter properly zeroed, proceed as follows:

(b) Ground the "LOW" terminal, and also connect the chassis, or case, to ground.

(c) Calibrate the meter as per Section (7), part (c), steps (I) through (VI). Very accurate calibration is not necessary at this point, so steps (d) and (e) of (7) may be disregarded.

(d) Zero the meter after calibrating, and then turn the Range Selector switch from the "100-CAL." to the 0.01 Full Scale Microamperes position. NOTE THE MAGNITUDE OF DEFLECTION OF THE NEEDLE (if any).

The meter is reading the residual grid current. This current can be either positive or negative, according to whether the residual current consists mainly of positive ions drawn to the grid and/or electrons emitted by the grid (positive meter deflection), or whether the residual current is predominantly negative ions impinging on the grid along with cathode-emitted electrons of thermal energy greater than the grid voltage, (negative meter deflection). Leakage current to the grid due to B+ voltages will also contribute to positive residual current indication.

If the residual current is less than 3 meter divisions, then no further adjustments need be made, and the Model 301 is again ready for use as a 5% or 3% full-scale accurate meter on all ranges (except possibly for the 0.01 range, if the zero shift is not corrected by the "ZERO ADJUST.")

If the zero shift is greater than 3 meter divisions, proceed as follows:

I. Note the direction and magnitude of the zero shift between extreme current ranges.

II. Return the Range Selector switch to the "100-CAL." position.

III. Note the position of the slot of the screwdriver-controlled rheostat, and turn the slot about 10° COUNTER-CLOCKWISE. The needle will start to drift.

IV. After the needle has stopped drifting, reset the zero and recalibrate, as per section (7), part (c), steps (I) through (VI).

V. Check for zero shift again, as discussed at the beginning of this section, (d), above.

If the zero shift checked in step (V) has decreased from that recorded in step (I) above, repeat steps (II), (III) and (IV) above, until a sufficiently low value of zero shift between extreme current ranges (or residual grid current) is achieved. If after step (V) an increase in zero shift is noted, then turn the rheostat CLOCKWISE 20°, and subsequently in steps of 10°, until the residual grid current is below the minimum desired.

If a residual grid current greater than 0.0005 microamperes (or 3 meter divisions on the 0.01 microampere full-scale range) persists in all positions of the rheostat, or if, in the process of reducing the residual grid current the tube becomes unbalanced so that the meter can no longer be brought to zero, then the 6SC7 tube must be discarded. A new 6SC7 must be put in place, and steps (a) en suite of this section repeated.

In general, when a 6SC7 is found that balances for zero and has low residual grid current, the residual grid current can usually be brought below 1 division, or about 0.0001 microampere, by careful adjustment of the cathode heater control rheostat. (In accurate work, this final adjustment should be made after the instrument has operated for at least one hour and is thoroughly warmed up.)

IT IS TO BE EMPHASIZED THAT THE CHECK FOR RESIDUAL GRID CURRENT MUST BE MADE WITH THE "LOW" INPUT TERMINAL AND THE CHASSIS GROUNDED.

(Although this tube selection for a proper 6SC7 may seem time-consuming, it actually should take less than one-half hour. The tube runs at approximately 60% of rated filament voltage, 40% of rated plate voltage and 10% of rated plate current, and so should last for many thousands of hours. Therefore, the necessity of replacing the 6SC7 should arise infrequently.)

****

NOTES

(To aid in obtaining the optimum performance and maximum usefulness of the Model 301 ELECTRONIC MICROAMMETER.)

1) For accurate readings, it is suggested that the instrument be calibrated each time it is turned off and on again.

2) DRIFT: If the Model 301 is to be used daily, and if the unavoidable drift for one-half hour or so after start is undesirable, it is suggested that the instrument be left running continuously. The wattage consumption is quite low (less than 40 watts), so the power cost is an unimportant consideration. In addition, because of the operation of all

tubes, resistors, capacitors and rectifiers well below ratings, there should be very infrequent parts replacements.

3) LINE VOLTAGE FLUCTUATIONS: In places where the line voltage is likely to fluctuate violently, it is recommended that the Model 301 be operated from a line voltage stabilizer of 40 to 60 volt-amperes rating. This is necessary to keep variations of 6SC7 heater voltage to a minimum, and reduce zero instability. The effect of line surges is particularly noticeable on the 0.01 range, as the residual grid current shows up on this range, and this residual current is very sensitive to 6SC7 heater voltage.

4) WHEN USING THE INSTRUMENT ON THE 0.01 SCALE, precautions may have to be taken to avoid spurious deflections of the meter due to induced voltages from moving electrostatically charged bodies nearby. Thus, on a dry day, the rustle of the user's clothing can readily generate enough static electricity to induce voltages on input circuit leads, and cause the output meter to deflect, if the leads are not shielded. This can be demonstrated on the 0.01 range by hanging a short length of lead to the "HIGH" terminal, with the "LOW" terminal grounded; pass a comb through the hair, and bring the comb towards the lead. As the comb approaches the lead, the needle will deflect; when motion stops, the needle will come back to zero. When the comb is withdrawn, the needle will deflect in the opposite direction. To show that the effects are truly due to static electricity, and are not "capacitative effects," one need only "wipe the charges off the comb" by passing the hand over the comb, and repeating the tests. The resulting deflections will be considerably reduced, or eliminated entirely.

Hence, for accurate and undisturbed readings on the 0.01 range, it is suggested that the leads to the "HIGH" terminal be shielded, and the shields grounded. If shielded lead cable is used, the insulation must be high compared to the 4 megohms input resistance, or leakage errors will be introduced. To this end, the use of polyethylene coaxial cable is recommended, with the outer conductor grounded.

5) WHEN USED IN AN ION GAUGE, the "SENSITIVITY" control will permit calibration of the Model 301 to read directly in microns. Thus, assume the ionization gauge tube has a sensitivity of 1.64 microamperes per micron at rated electrode voltages. Then, 1 micron = 1.64 microamperes, or 10 microns = 16.4 microamperes. If the sensitivity of the dc amplifier is reduced so that 164 microamperes are required for full-scale deflection on the 100 microampere range, or 16.4 microamperes on the 10 microampere range, it is apparent that the Model 301 is now indicating directly in microns. To achieve this reduction in sensitivity and calibration, proceed as in (7,c), steps (I) through (IV). However, at step (V) adjust the "SENSITIVITY" control not for full-scale deflection, but for 100/164, or 0.61 full-scale (a reading of 0.61 on the meter dial.)

It is apparent how this recalibration process can be applied for different pressure-current gauge constants.

It should be noted here that the high sensitivity of the Model 301 ELECTRONIC MICROAMMETER, (only 40 millivolts for full-scale deflection), makes it unnecessary to correct the grid or cathode voltage readings to correspond

to the ionization tube calibration. Since the plate is essentially at ground potential, (see Fig. 4,) the grid-ground and cathode-ground voltages are essentially the same as the grid-plate and cathode-plate voltages. This is, in general, not true for other dc amplifiers designed for low-current measurements, in which the input sensitivity is of the order of ½ to 1 volt. In such an instrument, as the pressure (and hence the plate current) changes, the plate voltage of the ionization gauge may vary as much as a volt, changing the plate-grid voltage, and correspondingly changing the pressure-plate current conversion factor. In accurate pressure measuring work, this source of error is not present when using your Model 301 ELECTRONIC MICROAMMETER.

6) FOR USE AS AN ULTRA-SENSITIVE VACUUM TUBE VOLTMETER, one need only employ a high-resistance probe connected to the "HIGH" input terminal to convert the Model 301 to a VTVM. Thus, with a 100 megohm probe, the full-scale sensitivity on the 0.01 microampere range is 1 volt, on the 0.1 microampere range the full-scale sensitivity is 10 volts, etc., up to 10,000 volts on the 100 microampere range. (The 4 megohm input resistance on the 0.01 microampere range must be corrected for in accurate work.)

For even greater sensitivity, a 1,000 megohm probe may be used, resulting in sensitivities of 10, 100, 1,000 and 10,000 volts on the 0.01, 0.1, 1.0 and 10 ranges. On the 100 microampere range, this corresponds to a sensitivity of 100,000 volts, a value impractical for ordinary probes. (The Beta Electronics Company is in a position to supply properly designed probes of resistance values up to 10,000 megohms and 30 Kv rating.)

A thorough investigation of high-resistance, high-voltage probes available commercially, has been conducted, revealing that, despite occasional claims of 2% accuracy, no such probe can be relied upon for accuracy better than 5%, especially on voltages above 100 volts. The inherent 5% error of the probe cannot be compensated for in dc Vacuum Tube Voltmeters of fixed sensitivity. However, with the Model 301 ELECTRONIC MICROAMMETER, the "SENSITIVITY" control can be used to compensate for the probe error, and thus bring the overall accuracy back to 2% (the output meter precision.)

To do this, one need only connect the Model 301 and the probe in parallel wi an accurate voltmeter across a source of voltage capable of operating the accurate voltmeter. (First check the zero setting of the Model 301.) Then turn on the source of voltage, and adjust the "SENSITIVITY" control until th accurate voltmeter reading and the ELECTRONIC MICROAMMETER reading are identical.

With this flexibility in sensitivity control inherent in the Model 301, the probe resistance can be almost any value, and accurate calibration can be made as a sensitive voltmeter. Thus, assume a probe of approximately 250 megohms is availabe. Then, at 100 volts, the current drawn will be 100/250 = 0.4 microamperes. So, put the probe in series with the "HIGH" input terminal, ground the "LOW" terminal, and connect the instrument in parallel with an accurate meter, such as a Weston Model 772 tester. Set the range to 0.1 microamperes, and apply about 90 volts to the two meters in parallel. The Model 301 will go off-scale. Turn the "SENSITIVITY" control counterclockwise until the reading of the Model 301 (considering it to be a 100 volt dc full-scale instrument) coincides with the accurate voltmeter reading

This is not
possible since
it must take
residents & visitors
because very non-Jewish
Blackwell

Then, the instrument will read 10, 100, 1,000 and 10,000 volts full scale on the 0.01, 0.1, 1.0 and 10 microampere ranges.

After making such a sensitivity calibration, the "SENSITIVITY" control must not be handled, or the calibration will be changed.

7) FOR FULL SCALE RANGES OTHER THAN 0.01, 0.1, 1.0, and 100 MICROAMPERES,

the "SENSITIVITY" control again makes the Model 301 an unusually flexible instrument. Assume it is desired to have full-scale ranges of 4.0 microamperes, or 0.4 microamperes, etc. Then, proceed as in (7,c), Steps (I) through (IV). At Step (V), instead of adjusting for full-scale deflection, adjust for $\frac{1}{4}$ scale deflection, or a reading of 0.25 on the dial face. Thus, with 100 microamperes flowing through the 100 microamperes range resistor, (which is what Steps (7,c), (I) through (IV), establish), the needle deflects $\frac{1}{4}$ scale, or 400 microamperes are required for full scale deflection. The full scale values on all ranges have now been multiplied by 4.

It is apparent that the full-scale currents can be multiplied by 2, 2.5, 3, 4, 5, 6, etc., or any other value that may prove convenient for a special application.

Although the sensitivity of the Model 301 can be increased by means of the (SENSITIVITY" and "CALIBRATION ADJUSTMENT" controls to produce full-scale ranges as low as 0.006, 0.06, 0.6, 6 and 60 microamperes, this procedure is in general not recommended, as the zero instability is increased as the sensitivity increases. If decreased stability can be tolerated, however, the calibration is as follows. Assume it is desired to have full-scale values of 0.008, 0.08, 0.8, 8 and 80:

a) Proceed as in step (7,c, I).

b) Adjust the "CALIBRATION ADJUST" control until the meter is indicating 80 microamperes. Since the meter is a 200 microampere full-scale meter, $\frac{1}{2}$ scale, or 0.5 on the dial, is 100 microamperes, and 0.4 of full-scale, or 0.4 reading on the dial, is 80 microamperes. Adjust, then, for a reading of 0.4 on the scale.

c) Proceed with steps (7,c,III through VI). The needle is now deflecting full scale for 80 microamperes on the 100 microamperes range, and 8, 0.8, 0.08 and 0.008 microamperes on the remaining ranges.

The steps to calibrate for full-scale sensitivities of 0.006, 0.007, 0.0075, etc., can readily be deduced from the above. However, because of the decrease in stability that accompanies the increase in sensitivity, the range of increase has been deliberately kept low in the Model 301. The sensitivit can be increased by not much more than 2 by means of the "SENSITIVITY" control, and the "CALIBRATION ADJUST" control cannot reduce the input current on the "100-CAL." range to much less than 70 microamperes.

However, when the calibration is changed so as to DECREASE the sensitivity (as described at the beginning of this section), THE ZERO STABILITY IS IMPROVED, AND THE RESIDUAL GRID CURRENT BECOMES LESS NOTICEABLE.

8) CHANGING THE INPUT RESISTORS is another method of calibrating the instrument so as to yield full-scale current values that may be more convenient for any particular application. Thus, assume that it has been found that most currents to be measured are around 0.008, 0.04, 0.2 and 1.5 microamperes. Then, leave R17 unchanged. Alter R16 to be $40 \times 10^{-3} / 5 \times 10^{-8} = 8 \times 10^{5} = 800{,}000$ ohms, for a full-scale sensitivity of 0.05 microamperes. Alter R15 to be $40 \times 10^{-3} / 2.5 \times 10 = 16 \times 10^{4} = 160{,}000$ ohms, for a full-scale sensitivity of 0.25 microamperes. Change R14 to 20,000 ohms, for a full scale sensitivity of 2 microamperes. R13, the 400 ohm resistor, must be left unchanged, so that proper calibration can be made at all times. The ELECTRONIC MICROAMMETER now has full-scale ranges of 0.01, 0.05, 0.25, 2.0 and 100 microamperes.

If it is remembered that the input sensitivity is 40 millivolts for full-scale deflection, when the instrument is calibrated on the "100-CAL." position, the required resistor for any full-scale range, in another position, can be calculated.

9) FOR FULL SCALE SENSITIVITY OF 0.001 MICROAMPERE, an input resistance of 40 megohms is required. Such a resistor may be inserted in place of R14, 15, 16 or 17. In general, however, the zero stability on the range will be adversely affected. Very careful adjustment of P4 will be needed to reduce the residual grid current to less than 5% of full scale, or 0.00005 microampere (5×10^{-11} amperes), and the Model 301 will have to be operated from a line voltage stabilizer.

Although the work involved in getting the ELECTRONIC MICROAMMETER to operate stably with 40 megohms input resistance may be tedious, the energy expended will be well rewarded by securing an instrument with sensitivity unmatched by any other microammeter of comparable cost, size and ruggedness, whether Electronic or otherwise.

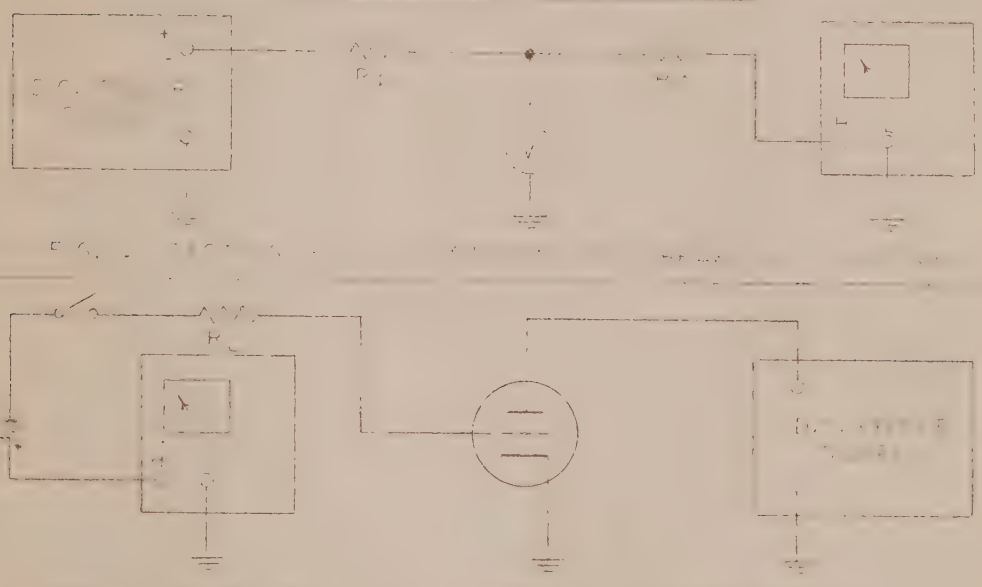
10) OVERLOAD LIMITS: The only elements of the Model 301 ELECTRONIC MICROAMMETER circuit that can be damaged by overloads are the input resistors R13 to R17, the grid protective resistor R18 and the input 6SC7 tube. The input resistors are rated at 1 watt. Therefore, on the 100 microamperes range, the maximum possible sustained current is 50 milliamperes, or the input voltage may be as high as $50 \times 10^{-3} \times 400 = 20$ volts. Voltages above this will burn out R13, without damaging R18 or VT3.

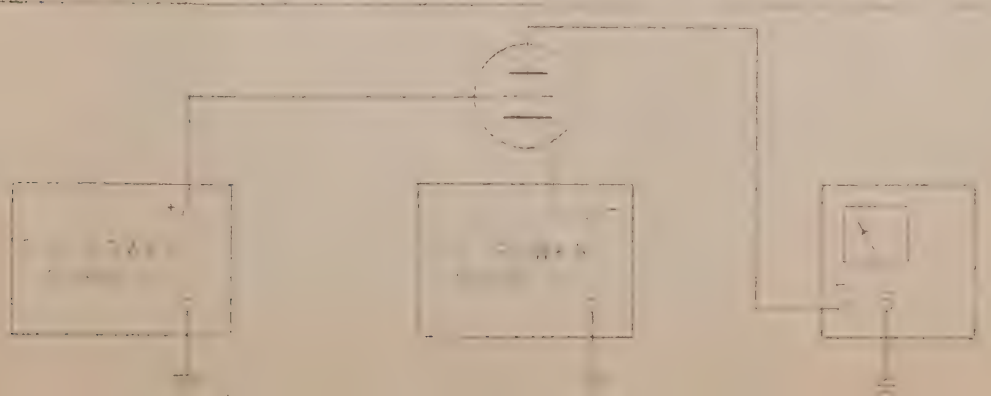
On the 10 microamperes range, the input resistance is 4,000 ohms, so that th maximum permissible current is about 16 milliamperes. The voltage is thus about 65 volts. This voltage is not enough to damage VT3.

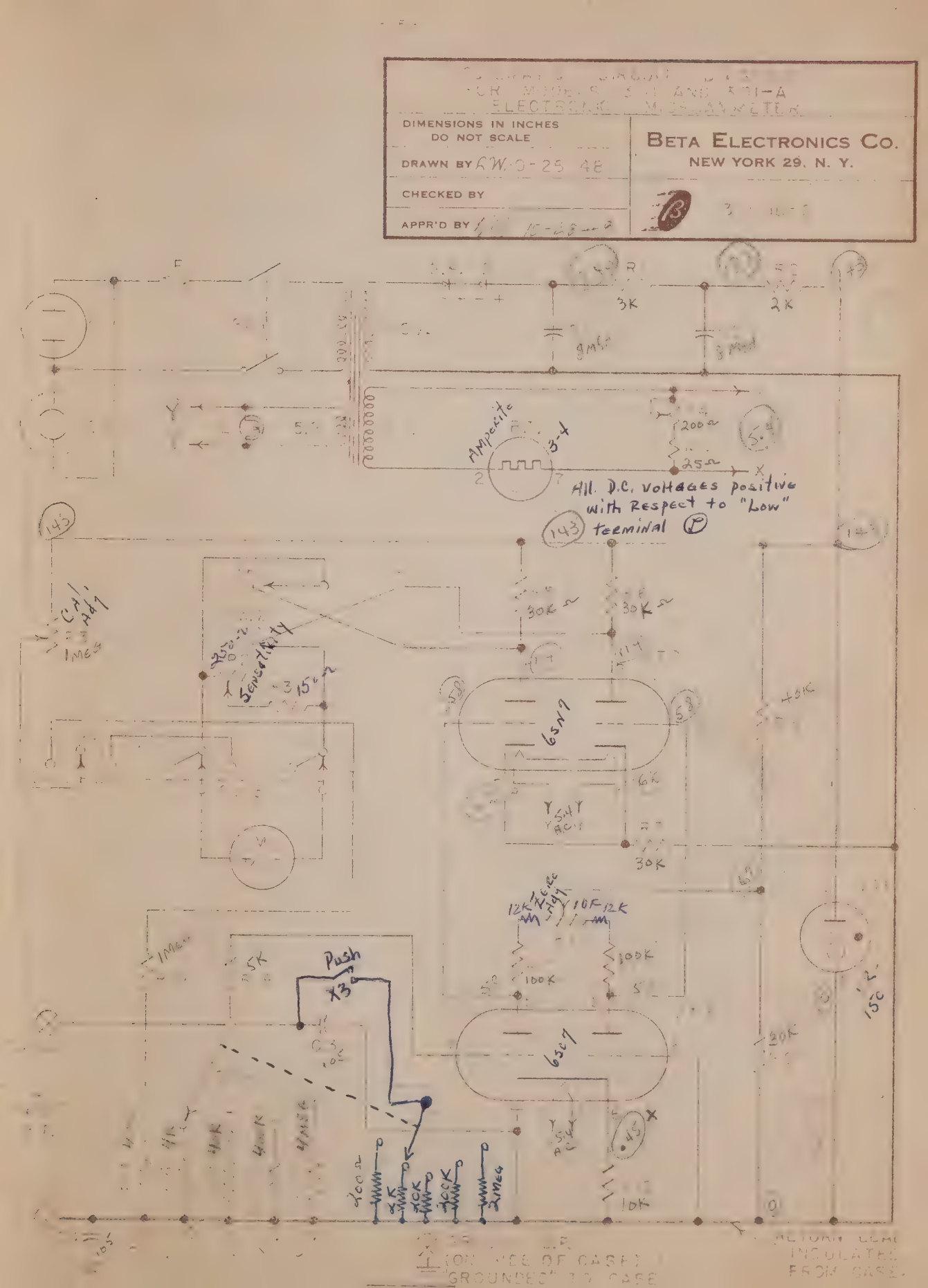
On the 1 microampere range, the maximum permissible voltage, from a wattage dissipation viewpoint, is about 200 volts. However, such a grid voltage would probably damage R18, and would injure the 6SC7.

Therefore, on the 0.01, 0.1 and 1.0 microampere full scale ranges, care must be taken to prevent the input terminal voltage from rising above about 100 volts, even momentarily, to prevent damage to the 6SC7. On the 10 and 100 ranges, the input voltage must be kept below 65 and 20 volts, respectively, to avoid damage to the input shunts.

DIMENSIONS IN INCHES DO NOT SCALE	BETA ELECTRONICS CO. NEW YORK 29, N. Y.
DRAWN BY [illegible]	
CHECKED BY	
APPR'D BY	301-1B-1






DIMENSIONS IN INCHES
DO NOT SCALE
DRAWN BY
CHECKED BY
APPR'D BY
BETA ELECTRONICS CO.
NEW YORK 29, N. Y.
3K
2K
Amperite
200Ω
25Ω
All D.C. voltages positive with Respect to "Low" terminal
30K
6SN7
6K
30K
12K
100K
300K
6SC7
Push
X3
20K
10K
GROUNDED TO CASE

MODEL 301 and 301A ELECTRONIC MICROAMMETER operating instructions.

PARTS LIST

Item	Function
B.P. - NC type FWG binding posts	Input terminals
B.T. - Amperite type #3-4 ballast	Emission stabilizer
C_1,C_2- 8-8mfd, 250 wv electrol.	Filter capacitors
C_3,C_4- 0.05,400 wv paper	Stray a.c. pickup suppressors
F - 2 amp type 8AG Littelfuse	Power fuse
M - 200 microamp 4" panel meter	Output meter
L - 6.3 volt pilot light assembly	"Power on" indicator
P_1- 50,000 ohms ww	"ZERO ADJUSTMENT" control
P_2- 1,000 ohms	"SENSITIVITY" control
P_3- 1 megohm	"CALIBRATION ADJUSTMENT" fine control
P_4- 200 ohms, ww	6SC7 Characteristics Control
R_1 - 3,000 ohms, wire wound 10W	Plate Voltage filter resistor
R_2 - 2,000 ohms, " " "	" " " "
R_3 - 75 ohms, 1w " " "	Minimum "SENSITIVITY" control
R_4 - 25 ohms, " " "	Heater voltage dropping resistor
R_5R_6 - 30 K. wire wound 10w	Output stage amplifier loads
R_7 - 30K " " "	Output stage cathode resistor (feedback)
R_8 - 40K " " "	Voltage divider for input stage plate supply
R_9 - 30K " " "	
R_{10},R_{11} - 100K wire wound	Input stage amplifier loads
R_{12} - 10K	Input stage cathode resistor (feedback)
R_{13} - 400 ohms, precision 1%	100 microamperes and "CALIBRATION" range resistor
R_{14} - 4000 ohms, precision 1%	10 microamperes range input resistor
R_{15} - 40,000 ohms, precision 1%	1 microampere range input resistor
R_{16} - 400,000 ohms, precision 1% (selected)	0.1 microampere range input resistor
R_{17} - 4 megohms, composition selected for 2% (In Model 301-A, this is 1%)	0.01 microampere range input resistor
R_{18} - 5K, 2W	Grid protective resistor
R_{19} - 1 meg, 1w	"CALIBRATION" current rough control
S_1 - 61M10 Amphenol input plug	Power input connector
S_2 - 61F Amphenol output socket	Auxiliary power outlet
S.R.$_{1,2}$ - Fed. Tel. & Rad. type #403D2625 Selenium Rectifier	D.C. power supply rectifiers
SW_1 - DPST toggle	"On-off" switch
SW_2 - DPDT rotary	"Plus-Minus" switch
SW_3 - 3 pole 3 position selector, shown in "OPERATE" position	"CALIBRATE-OPERATE-ADJUST" selector switch
SW - 2 pole, 5 position steatite	Range selector switch.

CONTINUED --
MODEL 301 and 301A ELECTRONIC MICROAMMETER operating instructions.

T_1 - 115/200,10, 5.9V	Power and filament transformer
VT_1 -VR 150	Voltage stabilizer
VT_2 -6SN7-GT	Current amplifier stage
VT_3 -6SC7	Voltage amplifier and impedance conversion stage

****

LAYOUT OF COMPONENTS ON TOP OF CHASSIS